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Terracon: An Automatic Graphics Database Conversion Program for Joint Tactical Simulation Databases

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Terracon: An Automatic Graphics Database Conversion Program for Joint Tactical Simulation Databases

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Abstract

The Joint Tactical Simulation (JTS) is a distributed, stochastic, entity-level, real-time, interactive simulation, developed by the Lawrence Livermore National Laboratory (LLNL). JTS provides the user with a two-dimensional (2-D) view of its simulation with a capability to zoom in or out. The U.S. Army Research Laboratory (ARL) has developed a visualization tool for viewing JTS in three dimensions. In support of this visualization tool, ARL has developed a UNIX-based, command-line program, Terracon, which automatically converts a JTS database into a three-dimensional (3-D) graphics database for use with the visualization tool.

Acknowledgments

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1. Introduction

At the request of the 7th U.S. Army Training Center, the U.S. Army Research Laboratory (ARL) has developed a visualization tool for viewing the Joint Tactical Simulation (JTS) in three dimensions. JTS is a distributed, stochastic, entity-level, real-time, interactive simulation, developed by the Lawrence Livermore National Laboratory (LLNL) [1]. JTS provides the user with a two-dimensional (2-D) view of the simulation with a capability to zoom in or out. The visualization tool runs on a Silicon Graphics, Inc. (SGI) computer platform and is based on a modified version of NPSNET, a public domain virtual reality (VR) simulation system with networking capabilities developed by the Naval Postgraduate School (NPS) [2]. The visualization tool provides a three-dimensional (3-D) view of JTS databases, as well as Distributed Interactive Simulation (DIS) entities from other DIS-compliant simulations. While the JTS itself is not DIS compliant, the JTS entities may be viewed in the visualization tool by the use of an ARL-developed communications bridge, the JTS-DIS bridge. The JTS-DIS bridge converts JTS network broadcast entities into DIS-compliant entities and converts other broadcast DIS entities into JTS entities.

In order to visualize a JTS database in the visualization tool, it is necessary to convert the JTS database into a format that may be read and understood by the visualization program. ARL has developed a UNIX-based, command-line program, Terracon, which automatically converts a JTS database into the Super Viewer (SV) 3-D format or the OpenFlight format, both of which can be displayed in the visualization tool. The SV format is a nonproprietary format developed by SGI [3]. The OpenFlight format is the property of MultiGen Inc., and is used in this program under a nonexclusive, nontransferable limited rights agreement with MultiGen Inc. [4].

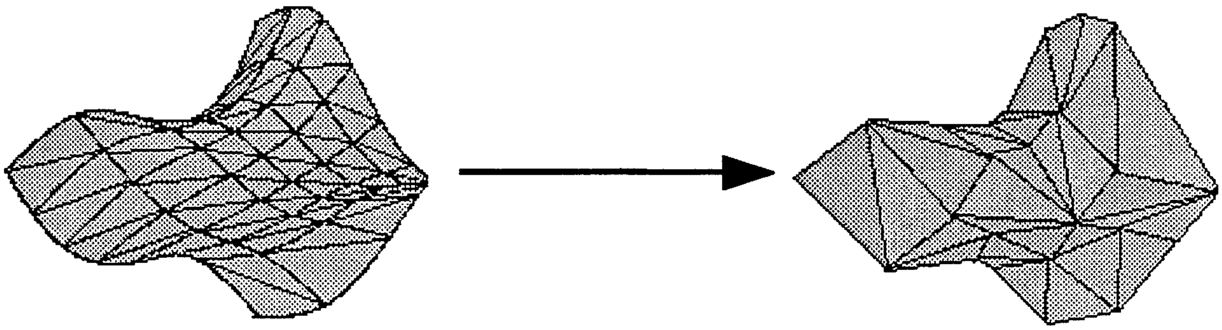
2. General

A JTS database consists of a list of elevation postings (or nodes) that describe a rectangular grid-based terrain and information specifying classes of cultural feature attributes by type. A class feature type can include data, such as material type and feature height. In addition, each instance of a cultural feature is represented by a data set that contains the feature's type, as well as a list of 2-D coordinate nodes that specify the feature's 2-D shape and location. The cultural features supported by JTS are roads, rivers, lakes, buildings, vegetation areas, urban areas, and fences (obstacles).

Terracon was developed in the C and C++ programming languages, using both in-house developed code, as well as nonproprietary code, to convert JTS databases to the SV or OpenFlight format for display in the visualization tool. The initial reading and storing into variable structures of a JTS database file is accomplished by the use of code originally written for JTS by LLNL. The conversion of JTS data into 3-D geometry data is accomplished by the use of code written in-house at ARL, except where otherwise noted. The overall conversion process performed by Terracon and examples of its performance on sample data are presented in the following sections.

2.1 Reduction of Terrain Elevation Data. An average JTS database may contain on the order of one million elevation postings. While this poses no problems for JTS itself, it does present a problem for the visualization of such a terrain on lower-end computers with limited processing ability. For example, to represent a terrain data set consisting of 1,001 * 1,001 elevations in a rectangular grid, it would be necessary to generate two million polygons. Using such a large number of polygons to display the terrain alone would make the visualization tool practically unusable on lower-end computers whose capabilities to display large numbers of polygons can be significantly limited. The inclusion of an algorithm in the conversion process, by which the number of polygons used to represent the terrain could be significantly reduced, would

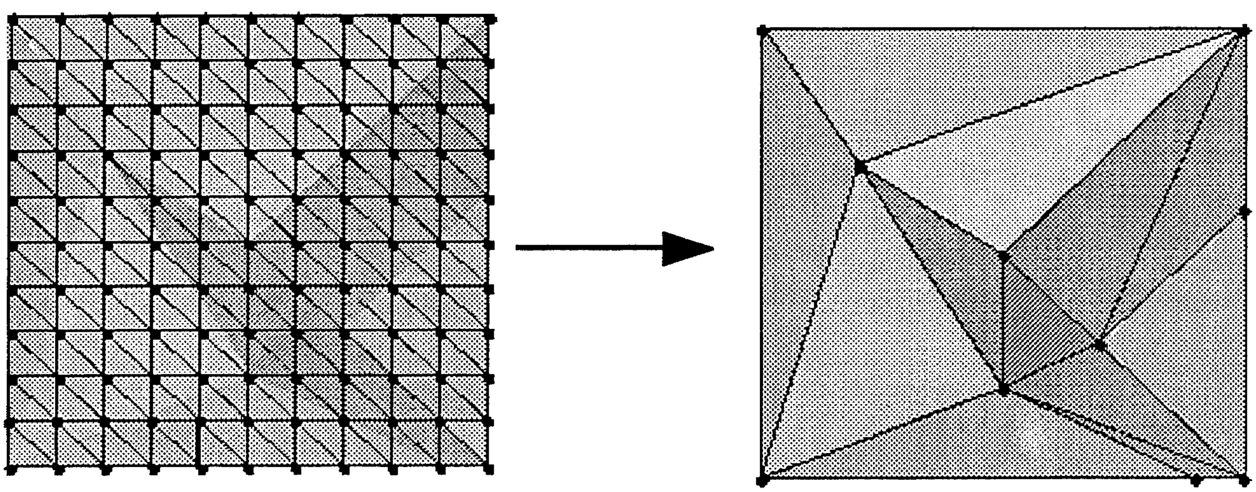
greatly improve the performance of the visualization tool on any computer on which it can be compiled (see Figure 1).



(a) (b)

Figure 1. Conceptual Terrain Reduction.
Conceptual Representation of Reduction of 3-D Terrain Data (a) Before Reduction and (b) After.

Terracon reduces the original terrain postings data by 95% and maintains an acceptable approximation of the terrain's geometry by means of a public domain algorithm and in-house modified code, Scape, made available by its authors, Garland and Heckbert [5]. Scape uses a greedy insertion algorithm to reduce the amount of original terrain data. The reduced terrain dataset is output as a triangulated irregular network (TIN) and is temporarily stored in a data structure by Terracon in preparation for the incorporation of certain JTS feature data into the reduced terrain data set (see Figure 2).



(a) (b)

Figure 2. Terrain Node Reduction.
Representation of Terrain Node Data (a) Before Reduction and (b) After Reduction by Use of Modified Scape Code.

2.2 Incorporation of Feature Data Into Terrain. When generating a 3-D terrain that contains cultural features, such as roads, rivers, lakes, and building footprints, it is common to simply create a separate set of polygons corresponding to the shape of the terrain and include that set as a model separate from the terrain. The problem with this method is that wherever feature data are represented on the terrain, there would actually be two identical sets of polygons that are coincident. When these coincident polygons are rendered by a computer, a strobing or tearing effect occurs. This effect is a result of a computer's graphics engine attempting to render the two sets of polygons at the same location and subsequently displaying random, alternating pieces of each set. Thus, areas of coplanar, coincident polygons appear as mottled surfaces that vary in appearance as the viewpoint is changed.

Though the JTS is a 3-D simulation (aside from its viewing capabilities), JTS databases do not contain elevation information for each of a feature's nodes, though they can associate a relative height of the feature (i.e., a building's height) with the feature's type. Cultural features are either represented by a list of 2-D coordinate nodes that define a series of line segments that form a closed area (i.e., a lake) or an unclosed area (i.e., a fence). The elevations of feature nodes are extrapolated from the elevation of the terrain at each node's 2-D coordinate. For example, the elevations of a one-story building's base nodes would be calculated by determining the height of the terrain at each building base node and using that terrain elevation as that node's elevation. Visually, this method of calculating the elevations of cultural features' nodes is sufficient for creating a 2-D bird's-eye view of the simulation database just as the JTS provides. However, if the same method was used to generate true 3-D geometry for display, unrealistic looking features (i.e., roads on the sides of mountains) would be created.

These problems are overcome by first adding road, river, lake, and building nodes to the set of reduced terrain nodes. Next, any nodes in the terrain dataset that are bounded by a closed-area feature are removed and intersecting segments of the added features are divided into separate segments, and new nodes added, until all intersections are eliminated (see Figure 3).

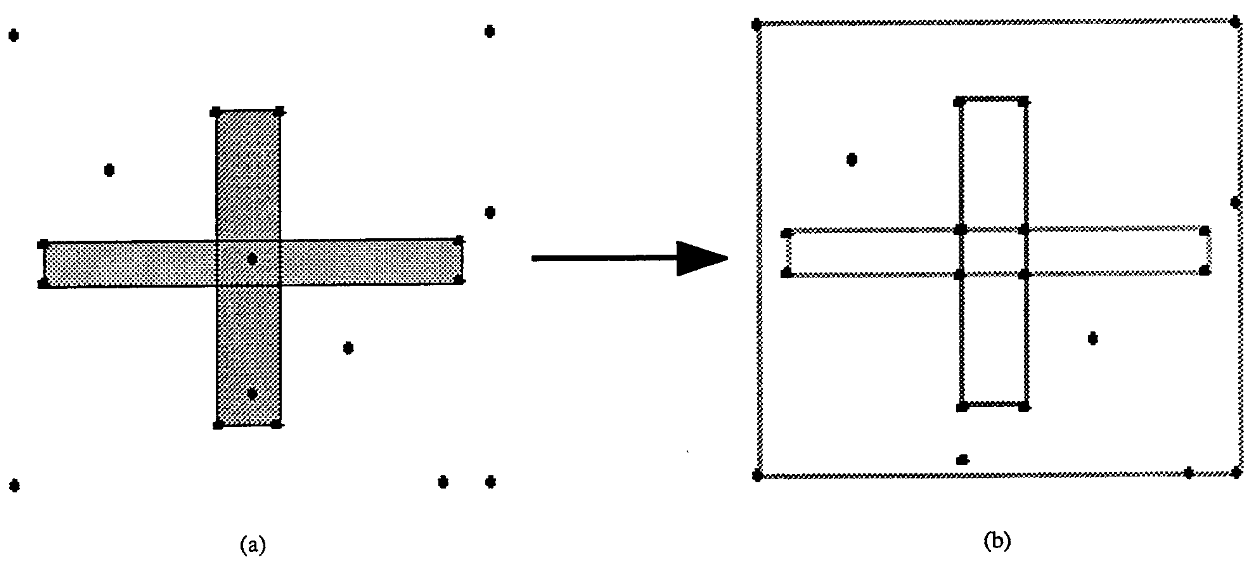
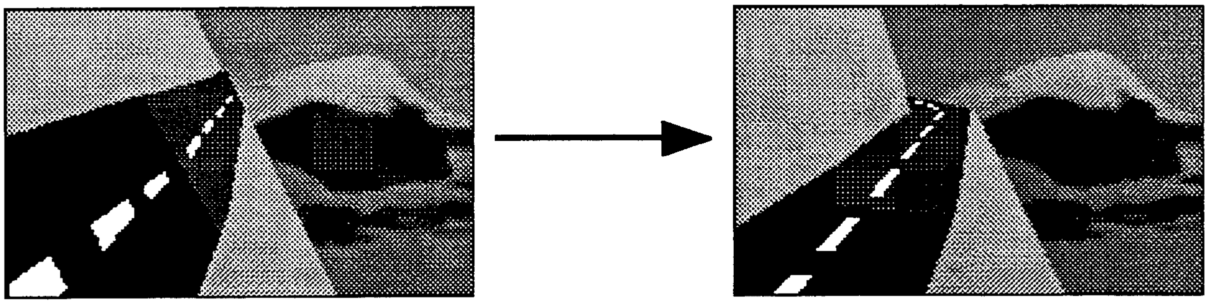


Figure 3. Incorporation of Feature Data.
Example Showing (a) a Road and River Section to be Incorporated Into Terrain and (b) the Result After Removing Feature Bounded Nodes and the Addition of Nodes to Eliminate Feature Segment Intersections.

In addition to the inclusion of these features' nodes into the reduced terrain data set, these same features are flattened with respect to the terrain by setting a common elevation for subsets of a feature's nodes. For example, Terracon determines the lowest elevation of the two coordinate node elevations that define one end of a road or river section and sets both elevations to this lower number. The result is that the end of the section is oriented so as to be parallel to the x-y coordinate plane. Because these section nodes are actually included in the terrain dataset, the result is that the terrain is modified to include a flattened area corresponding to the location of the section ends. In addition, intersections between road or river sections and the reduced terrain are determined and included in the corresponding section's boundary data set. The result is that roads and rivers more closely follow or flow across the terrain (see Figure 4).



(a) (b)

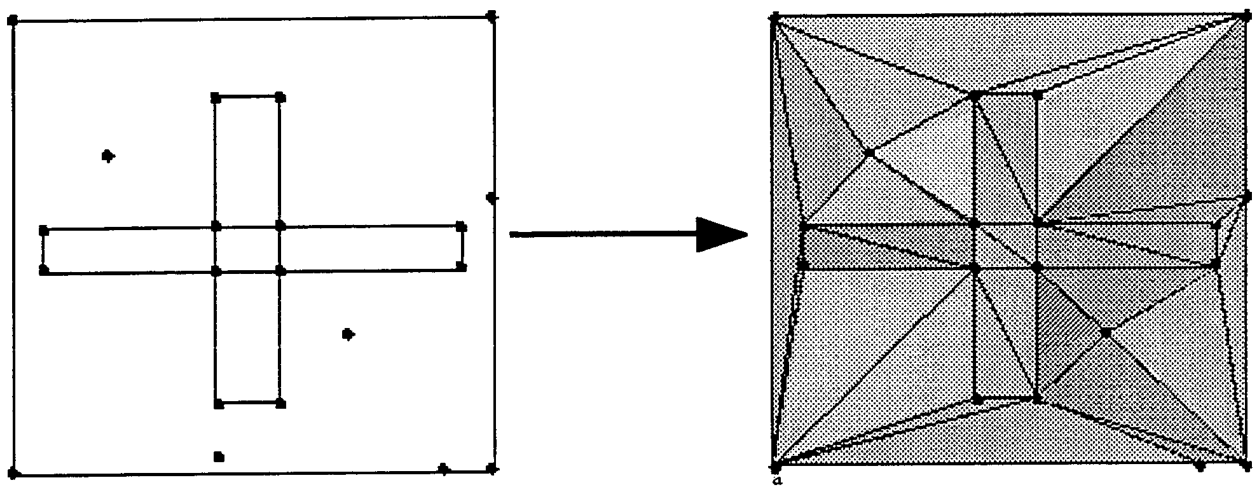
Figure 4. Horizontal Feature Orientation.
Example Showing Road Geometry Created Using (a) Original Node Elevations and (b) Horizontally Oriented End Nodes.

2.3 Triangulation of the Feature-Included Terrain. At this point in the process, the feature-included terrain data set created by the addition of features' nodes must be triangulated in order to generate a renderable, polygonal surface. In order to preserve the shapes of included features, as well as the rectangular shape of the terrain, it is necessary to use a triangulation algorithm that allows the specification of required segments in the final triangulation. For example, specifying that the line segments connecting the four nodes of a road section be included the final triangulation ensures that after processing, there will be a subset of triangular polygons that correspond to the original road section's shape.

Terracon triangulates the reduced terrain, building, road, river, and lake nodes and specified required segments by means of an algorithm and in-house modified code, Triangle, made available for noncommercial work by its author, Shewchuk [6]. The resulting triangulation is used to generate the output file, which will contain the 3-D coordinate information describing the set of triangular polygons necessary to render the new feature-included terrain.

The features incorporated into the terrain are now represented in the resultant output file by subsets of terrain polygons. In order for individual features to be colored and texture mapped (apply image data to sets of polygons) according to their type, it is necessary to identify what subsets of terrain polygons should be associated with what feature. This is done by comparing each terrain polygon in the final triangulation with a list of the original features' boundaries. Specifically, a function is used to determine if a terrain polygon's calculated centroid is bounded by an original feature's closed-area boundary.

As a terrain polygon may be bounded by more than one type of closed-area feature, an order of precedence is used to determine that polygon's overall type. For example, if a terrain polygon's centroid is found to be bounded by a river section that polygon would be classified as a river polygon. However, if this same polygon is also found to be bounded by a road section, the polygon's type would be set to that of a road polygon. In this particular example, road polygons take precedence over river polygons in the assumption that roads will tend to cross over rivers instead of under them. By this method, it is possible to group subsets of terrain polygons into separate model files that only represent roads, rivers, lakes, or building footprints (see Figure 5).

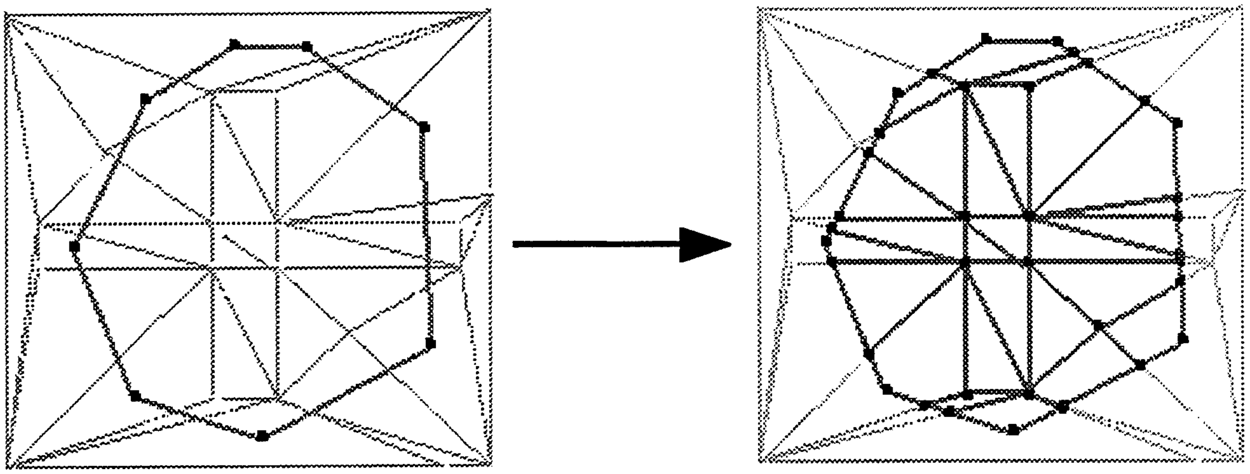


(a) (b)

Figure 5. Terrain Triangulation.
Example Showing Reduced Terrain, Including Modified Feature Data (a) Before Triangulation and (b) After.

2.4 Construction of Buildings. A JTS database's original building data sets consist of node data that describes linked segments that form a closed-boundary area. Making use of the building height as specified by its type, geometry describing walls and a flat roof are created. The previously flattened terrain corresponding to the building's footprint serves as the building's floor. Each converted building is written as a separate model to the output file.

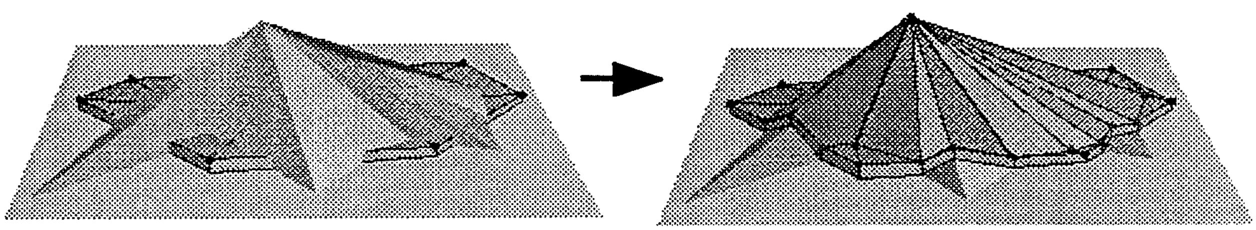
2.5 Construction of Vegetation and Urban Canopies and Fences. A JTS database's original fence, vegetation area, and urban area data consists of node data that describe linked segments. Vegetation and urban data describe closed-areas, while fences do not. In order that the generated 3D models of these features realistically follow the terrain, nodes are added which correspond to intersections between these feature segments and terrain segments defined by the final triangulation of the feature-included terrain data set (see Figure 6).



(a) (b)

Figure 6. Addition of Terrain-Corresponding Nodes.
Example Showing (a) Original Area Nodes and Segments and (b) Terrain-Corresponding Nodes and Segments Added.

In addition, for the vegetation and urban areas, terrain nodes and segments bounded by the closed-area data are included in each area feature's data set. By including these bounded nodes, a canopy of polygons may be created that mimics the terrain at the feature type's specified height. Each feature is written as a separate model to the output file (see Figures 7 and 8).



(a) (b)

Figure 7. Terrain-Following Features.
Representation of How Additional Data Converts (a) Non-Terrain-Following Features Into (b) Terrain-Following Features.

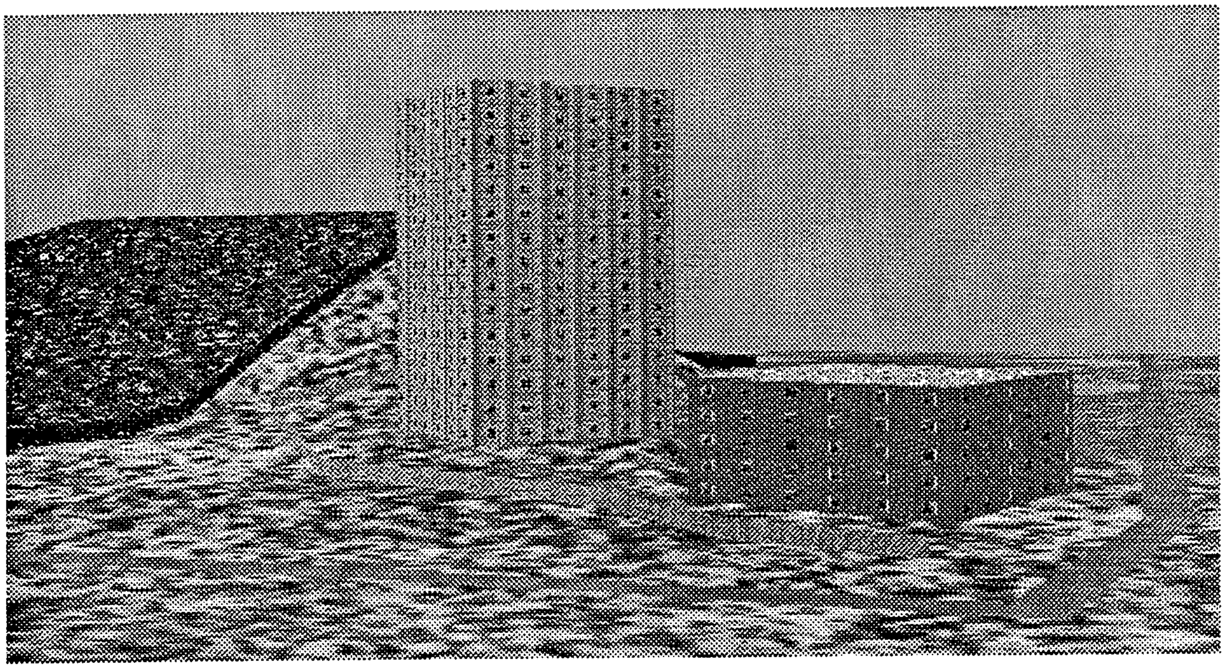


Figure 8. Converted Test Database, tinytown.flt, Showing Terrain-Following Features.

2.6 Automatic Texture Mapping of Feature Models. A JTS database contains information about classes of feature types. For example, a specific building's type may identify it as being constructed of wood. Based on a feature's type, a generic texture corresponding to the type is specified to be mapped onto the object to add additional realistic detail to the final 3-D geometry. Default textures are used for features without a specified type. Actual texture files need not be present during the conversion process (as textures are only specified by filename in the output files), but must be accessible by the visualization tool at run-time (see the appendix, and Figures 8, A-2 and A-4).

2.7 Performance. As an indication of Terracon's performance, the conversion program was used to convert three different JTS databases with varying numbers of terrain postings and cultural features on two different SGI computer platforms: an SGI Onyx with 4 * 200 MHz R4400 processors and an SGI Indigo II Extreme with a 1 * 150 MHz R4400 processor. Because Terracon does not make use of multiple processors, only a single central processing unit (CPU) was utilized when the program was run on the SGI Onyx system. Specific statistics about each database are listed in Table 1, along with the elapsed real time for each platform. Real times (actual CPU times) were calculated by running the UNIX command, *timex*, with the Terracon executable and a JTS database as arguments.

Table 1. Terracon Performance Comparison of JTS Databases.

JTS Database	navy_yard.DAF	grafenfels.DAF	sarajevo.DAF
Elevation Postings	48,841	250,531	1,002,001
Buildings	137	234	167
Roads	141	4,160	4,695
Rivers	1	1,175	2,015
Lakes	7	108	3
Vegetation Areas	8	3,047	2,572
City Areas	13	134	131
Fences	9	0	0
Triangular Polygons Created	10,893	266,749	550,352
Onyx Time (h:m:s)	0:0:11	0:28:30	1:47:57
Indigo Time (h:m:s)	0:0:15	0:40:20	2:22:13

3. Future Developments

While Terracon is a robust conversion tool and is currently being used by the 7th U.S. Army Training Center, there are a number of areas in which this tool can be improved. Some of these improvements are discussed in the following paragraphs.

One improvement would add the capability to control the percentage by which the original terrain data set is reduced. Currently, a 95% reduction is hard-coded into Terracon. Providing the user the ability to set the percentage of reduction would enable users with higher-end computer platforms to make use of higher-fidelity 3-D terrain databases if they so desire.

Additional improvements can also be made to the method by which buildings, vegetation canopies, and urban canopies are created. Currently, Terracon does not process some building, vegetation, and urban data sets. Specifically, these data sets are not converted if their coordinate nodes describe segments that intersect with themselves (self-intersecting features). This is more than a trivial problem, as there are many possible different cases of self-intersecting features. An examination of typical JTS databases shows that only a small fraction of building, vegetation, and urban features are self-intersecting. Modifying Terracon to handle these cases of self-intersection would remove the restriction currently set on users of the visualization tool to not create self-intersecting features.

Finally, not all of the data in a JTS database that might be converted by Terracon are converted. The original work request for a conversion program excluded JTS data that describes the interior walls, doors, and windows of buildings. As an improvement to the existing program, Terracon could be modified so that these data are converted to provide more detailed and accurate building models.

4. Conclusion

Terracon was developed to convert JTS databases to a 3-D format so that their contents might be viewed in the visualization tool. It provides a hands-off, automatic conversion process that reduces the original terrain data set by 95%; flattens and incorporates cultural features, such as roads into the terrain, generates vegetation, urban and fence models that realistically flow over the terrain; and applies generic texture maps to all generated models by feature type. The program provides reasonable performance as measured by conversion times on most SGI platforms. All code written for or incorporated into Terracon is nonproprietary and can thus be easily enhanced or expanded to meet the needs of current and future users.

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5. References

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2. Naval Postgraduate School. *NPSNET IV.9 User Guide*. 1996.

3. Silicon Graphics, Inc. *Iris Performer Programmer's Guide*, pages 311-314. 1995.

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5. Michael Garland and Paul S. Heckbert. *Fast Polygonal Approximation of Terrains and Height Fields*. 1995.

6. Jonathan Richard Shewchuk. *Triangle: Engineering a 2D Quality Mesh Generator and Delaunay Triangulator*. 1996.

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Appendix:

Screenshots Of Conversions

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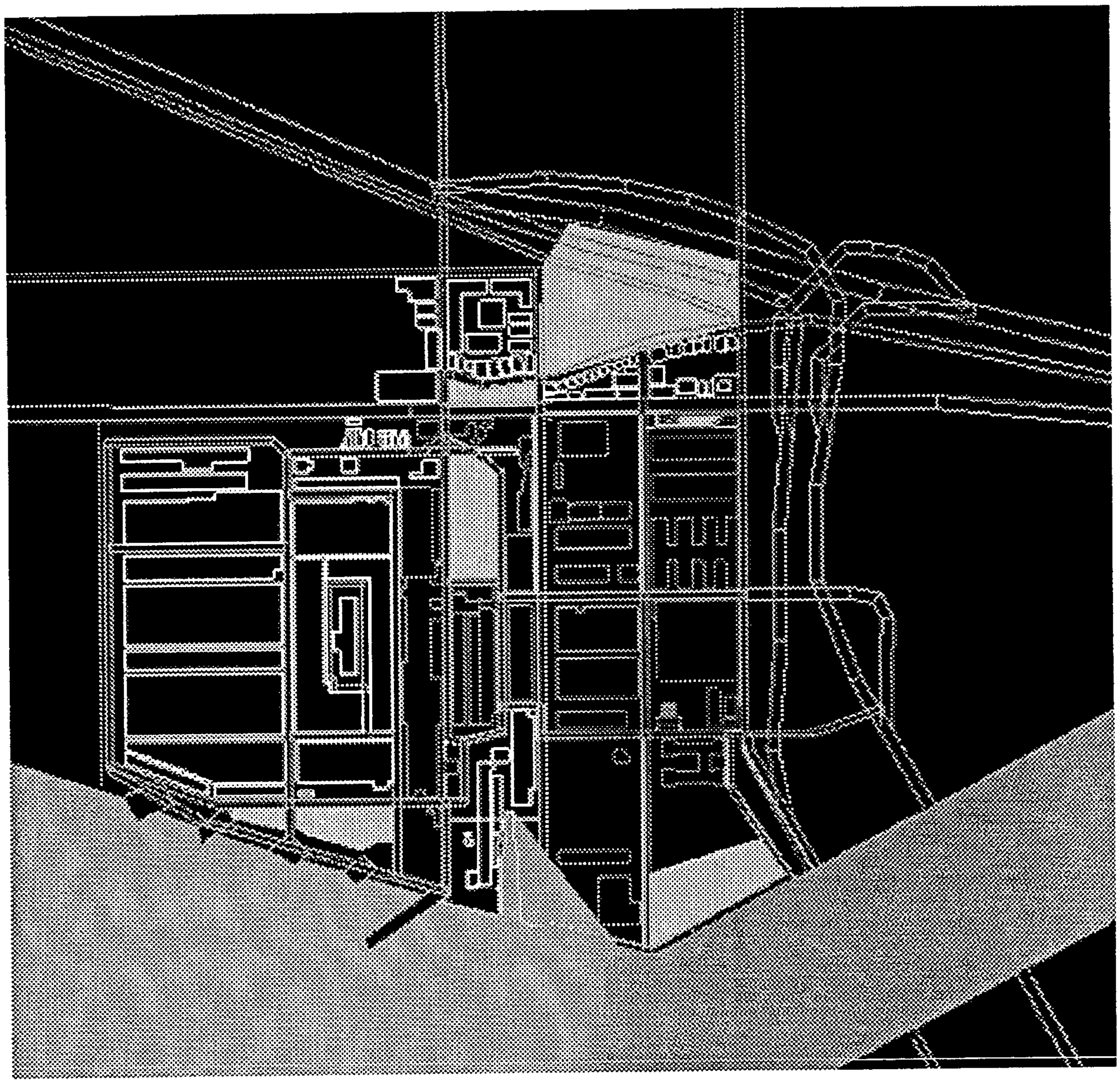

Figure A-1. 2-D View of JTS Database, navy_yard.DAF.

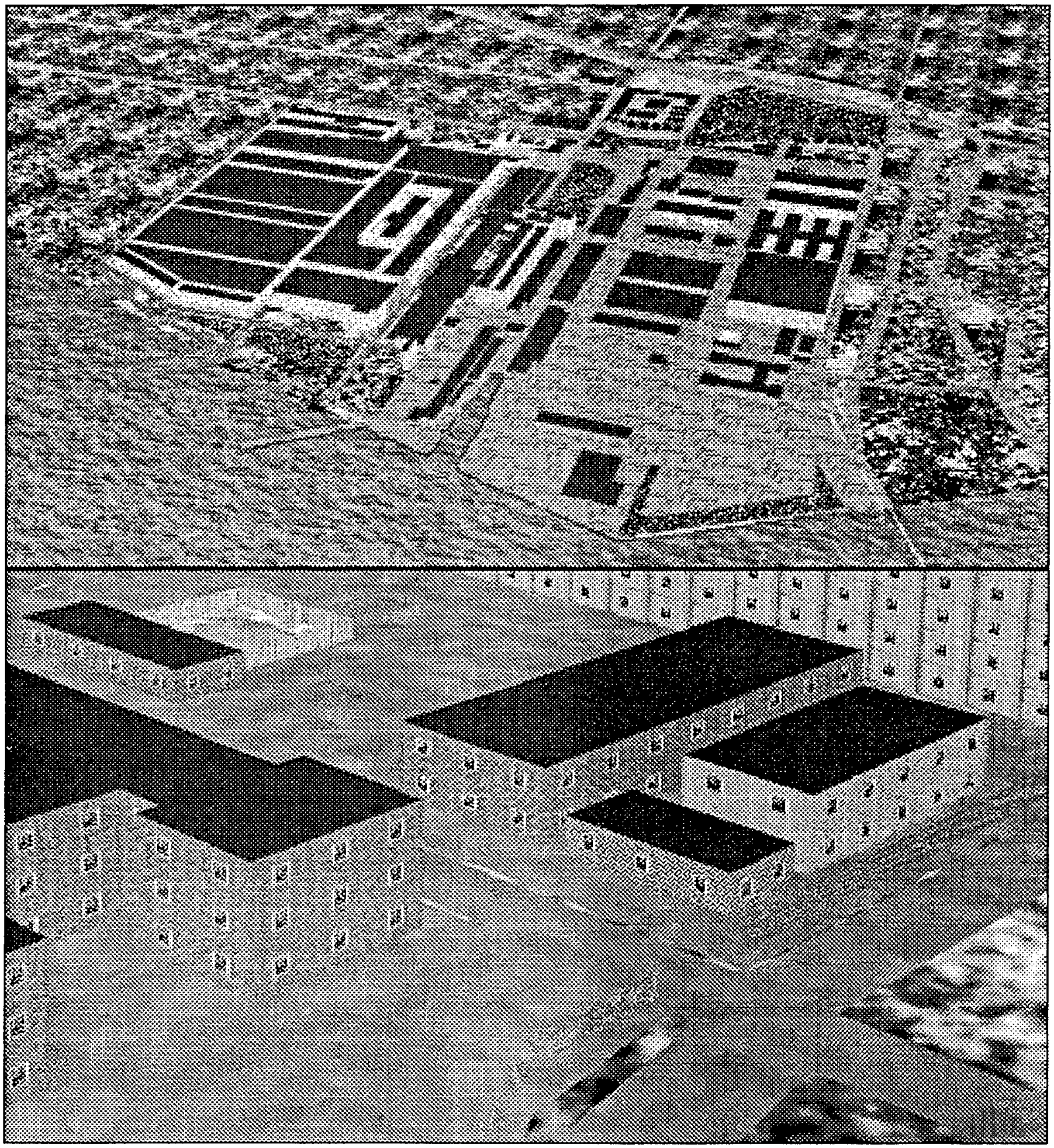

Figure A-2. 3-D Views of Terracon-Converted JTS Database, navy_yard.flt.

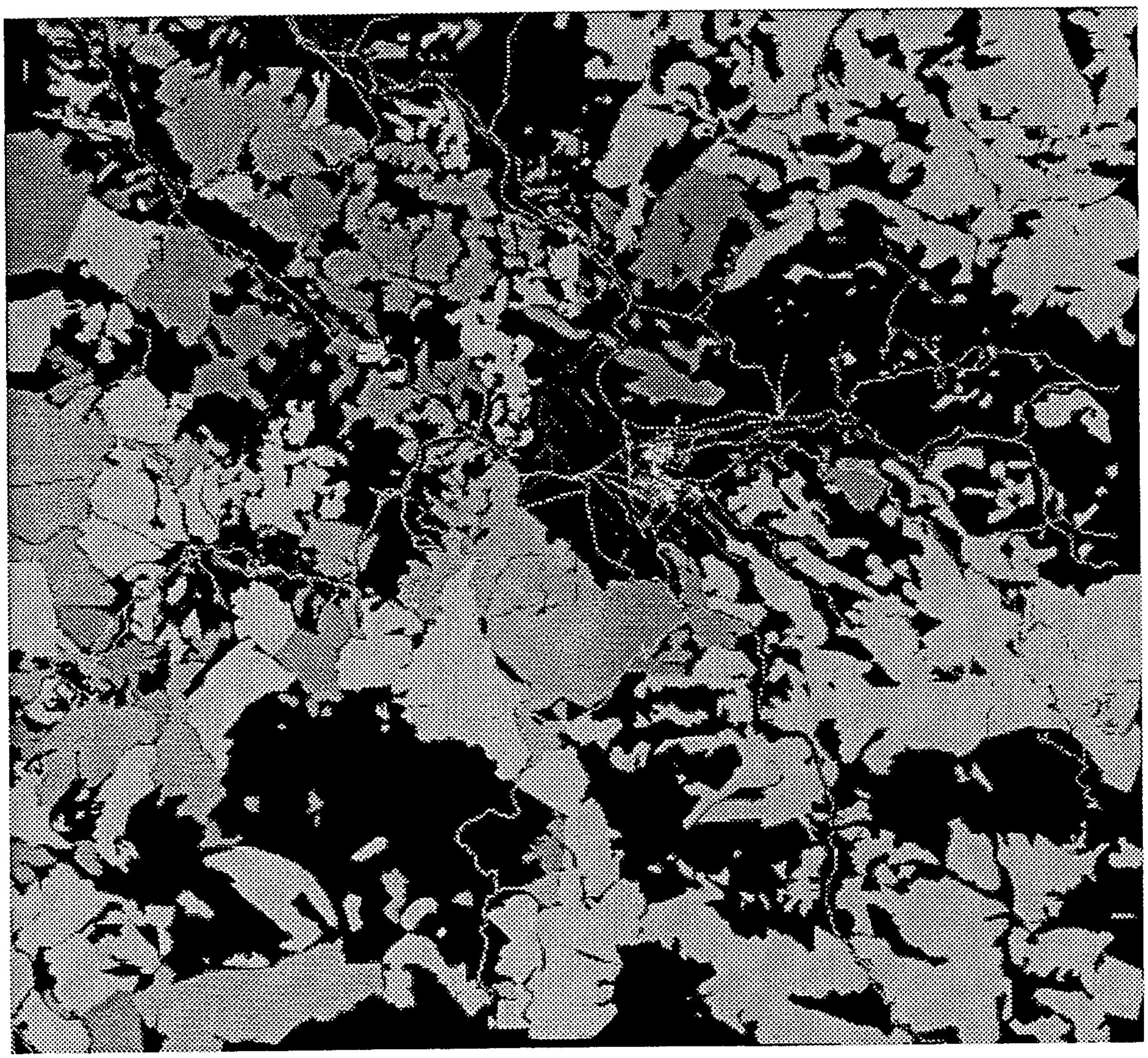

Figure A-3. 2-D View of JTS Database, sarajevo.DAF.

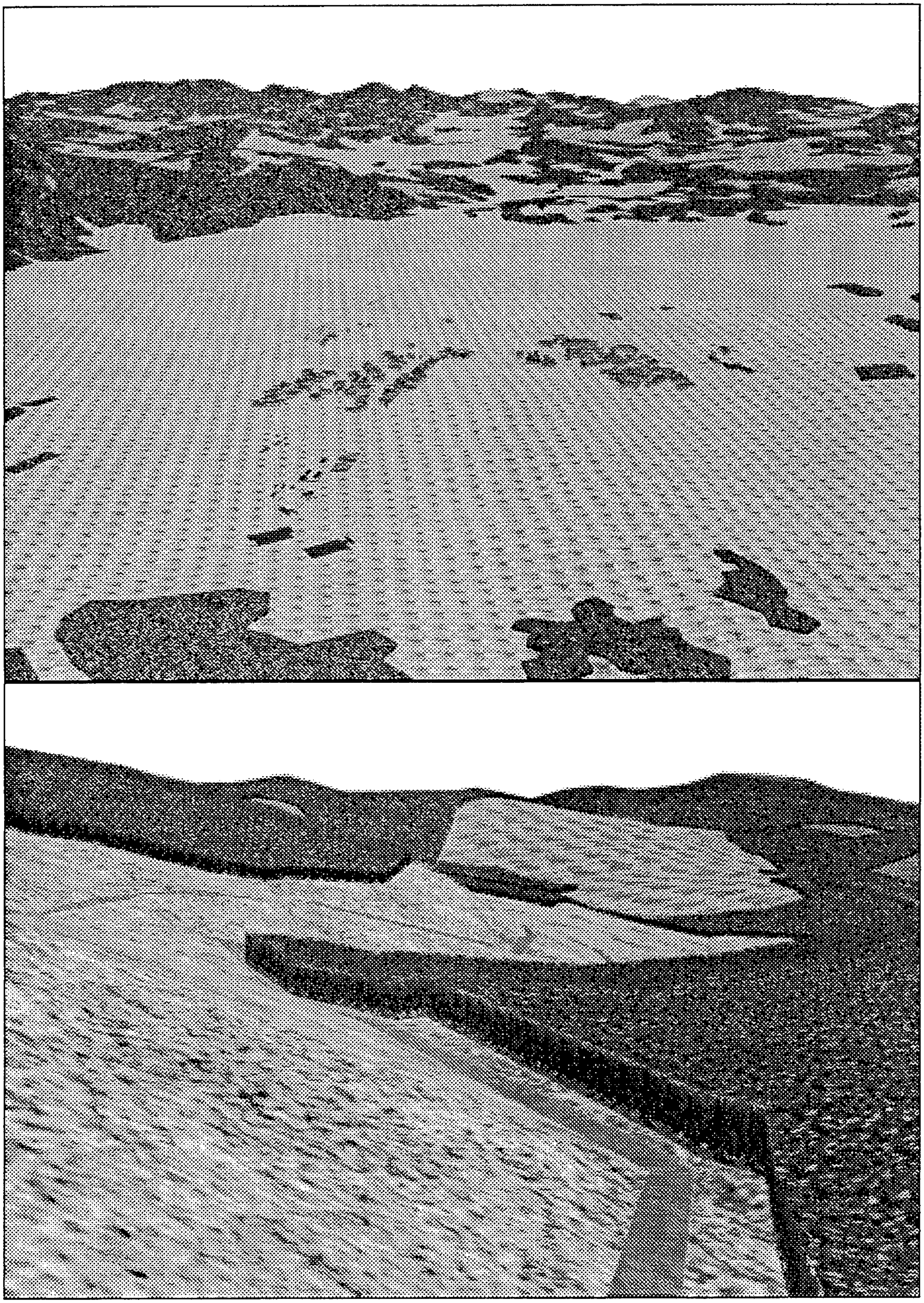

Figure A-4. 3-D Views of Terracon-Converted JTS Database, sarajevo.flt.

List Of Acronyms

2D	Two-Dimensional
3D	Three-Dimensional
ARL	U.S. Army Research Laboratory
CPU	Central Processing Unit
DIS	Distributed Interactive Simulation
JTS	Joint Tactical Simulation
LLNL	Lawrence Livermore National Laboratory
NPS	Naval Postgraduate School
SGI	Silicon Graphics Incorporated
SV	Super Viewer
TIN	Triangulated Irregular Network
VR	Virtual Reality

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13. ABSTRACT *(Maximum 200 words)*

The Joint Tactical Simulation (JTS) is a distributed, stochastic, entity-level, real-time, interactive simulation, developed by the Lawrence Livermore National Laboratory (LLNL). JTS provides the user with a two-dimensional (2-D) view of its simulation with a capability to zoom in or out. The U.S. Army Research Laboratory (ARL) has developed a visualization tool for viewing JTS in three dimensions. In support of this visualization tool, ARL has developed a UNIX-based, command-line program, Terracon, which automatically converts a JTS database into a three-dimensional (3-D) graphics database for use with the visualization tool.

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Street or P.O. Box No. ______

City, State, Zip Code ______

7. If indicating a Change of Address or Address Correction, please provide the Current or Correct address above and the Old or Incorrect address below.

OLD ADDRESS

Organization ______

Name ______

Street or P.O. Box No. ______

City, State, Zip Code ______

(Remove this sheet, fold as indicated, tape closed, and mail.)

(DO NOT STAPLE)

DEPARTMENT OF THE ARMY

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